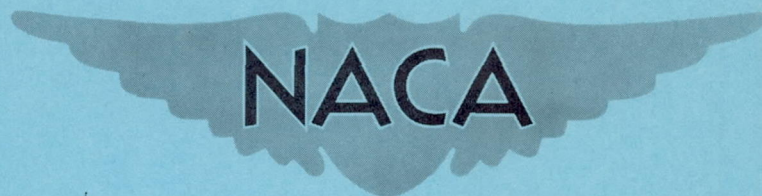


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# RESEARCH MEMORANDUM

INTERFEROMETER WITH LARGE WORKING FIELD

UTILIZING SCHLIEREN OPTICS

By Donald R. Buchele and Pierce B. Day

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Cleveland, Ohio

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## INTERFEROMETER WITH LARGE WORKING FIELD

## UTILIZING SCHLIEREN OPTICS

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## SUMMARY

The optical system of a new-type interferometer utilizing schlieren optics is described. In this instrument, former limits to the working-field size imposed by the practical size of conventional interferometer optics are removed. A conventional 24-inch-diameter schlieren instrument was converted to an interferometer and operated with an 18- by 18-inch supersonic tunnel. Interference photographs taken with the instrument are presented.

## INTRODUCTION

Application of the Mach-Zehnder interferometer to air-density measurement has established the essential validity of the data and the usefulness of the interference method in aerodynamics. The optics of the instrument, however, set a practical limitation to the size of the working field that could be attained. In particular, splitter plates larger than 16 inches in diameter are extremely expensive and are difficult to fabricate.

This practical limitation to interferometer size has been avoided by a number of new-type interferometers having large working fields but using small splitter plates (references 1 and 2). These designs, although using small splitter plates, require additional optical elements that complicate the structure of the instrument.

In an attempt to make larger installations both practicable and economically feasible, the optical elements and structural frame of a conventional 24-inch-diameter schlieren apparatus were converted to an interferometer. This instrument, operated with an 18- by 18-inch supersonic wind tunnel at the NACA Lewis laboratory, has produced fringes that are believed to be satisfactory for air-density measurement.



## DESCRIPTION OF OPTICAL SYSTEM

The optical system of a two-mirror schlieren apparatus that has been converted to an interferometer is shown in figure 1.

The conversion units (fig. 2) installed in place of the source and knife edge of the schlieren are identical. Each unit consists of a single splitter plate  $S$  and three mirrors  $M$  (fig. 1). In their initial position the four plates are mutually parallel and are oriented  $45^\circ$  to the optical center line. Along the center line, the distances  $M_2M_1S_1$  and  $M_2M_3S_1$  are equal. The distance between the schlieren mirror  $P_1$  and the splitter plate is adjusted so that the astigmatic focal line  $f$  coincides with the splitter plate.

With mirrors and splitter plates in initial positions and with the light source imaged at the surface of splitter plate  $S_1$ , half the parabola  $P_1$  is illuminated by light reflected from the splitter plate and the other half is illuminated by light transmitted through the splitter plate. When the splitter plate is rotated from its initial position through an angle  $\theta/2$ , where  $\theta$  is one-half the aperture ratio of the parabola, the test and reference beams in the tunnel are provided by the same half-cone  $\theta$  of the incident light beam. Every ray in the incident beam is divided by the splitter plate into two coherent rays of lesser intensity, one ray entering the test beam and one ray entering the reference beam. Corresponding points of the test and reference beam (cross-section A-A, fig. 1) are then coherent and will interfere. Interference is obtained by rotating splitter plate  $S_2$  through angle  $\theta/2$  causing the two beams to overlap (section B-B, fig. 1). This adjustment produces a fringe of infinite width. When nonmonochromatic light is used, it is necessary to adjust the two beams for zero path difference. This adjustment can be made by translating mirror  $M_6$ .

To adjust for finite fringe spacing with the fringes focused at the camera image and its conjugate plane at the tunnel, each pair of coherent rays must intersect at these planes. Starting at the infinite fringe adjustment with a zero angle, rotation of mirror  $M_6$  and splitter plate  $S_2$  is required (fig. 3). With rotation of mirror  $M_6$  through a small angle  $\alpha/2$ , the coherent rays no longer coincide but intersect at angle  $\alpha$  at  $M_6$ , distance  $a$  from  $S_2$ . To move this intersection point to the plane of the tunnel,  $S_2$  is rotated through angle  $\beta/2$ . The ratio  $\beta/\alpha$  can then be determined from the figure.



$$\beta = \alpha - \gamma$$

$$\gamma = \alpha \frac{a}{d}$$

$$\beta = \alpha - \alpha \frac{a}{d}$$

$$\frac{\beta}{\alpha} = 1 - \frac{a}{d}$$

Because the distance  $d$  is usually much greater than  $a$ , approximately equal rotation is required for  $M_6$  and  $S_2$ . In most two-mirror schlieren designs the tunnel is at the focal distance from parabola  $P_2$ . The optical distance  $d$  is then infinite, and  $\beta = \alpha$ . The equal angles suggest a gear or linkage for operating both plates by one control. Winkler has shown that similar methods are feasible for the Mach-Zehnder interferometer (reference 3).

To obtain fringes orientated in any other direction,  $M_6$  and  $S_2$  must each also rotate around an axis perpendicular to the first axis, with the second axis lying in the plane of figure 3 and also in the plane of the plate.

Summarizing then, the adjustments required to obtain fringes are: rotation of  $S_1$  about a vertical axis to obtain coherent rays, translation of  $M_6$  for zero optical path difference, and rotation of  $M_6$  and  $S_2$  about two perpendicular axes lying in their reflecting surfaces.

#### ADJUSTMENT OF OPTICAL COMPONENTS

A 3/16-inch-diameter aperture plate was installed on the optical center line adjacent to splitter  $S_1$  and between  $S_1$  and the condensing lens, thereby providing an effective light source sharply defined in size and having a maximum intensity (fig. 1). The focus of the parabolic mirror was then adjusted to coincide with the plane of the aperture. With light from the source focused upon the aperture, the entire unit was rotated so that the light beam was centered upon the parabolic mirror and the unit was bolted to the pedestal. The light, after passing through the tunnel and reflecting from the second parabolic mirror, converged through the second conversion unit that was placed with its splitter plate at the focus of the light



beam. The unit was then rotated so that the edge of mirror  $M_5$  precisely divided the two incident beams while their focal points remained centered upon the splitter plate and the unit was bolted to the pedestal.

The amount of rotation  $\theta/2$  of splitter plate  $S_1$  was determined by sighting from the extinguished light source through the conversion unit and rotating  $S_1$  until the two halves of the tunnel overlapped, shown in section B-B in figure 1. Adjustment for interference was made at the second conversion unit by the same technique used with the Mach-Zehnder interferometer; that is, a sodium lamp was placed behind the B-H6 lamp, which was then removed. A small instrument lamp was placed between the condensing lens and the sodium lamp, and a second instrument lamp was placed close to splitter  $S_1$  between the splitter and the aperture plate. With the camera removed, a double image of each instrument lamp was seen by sighting through  $S_2$ . The double images appearing at  $S_2$  were made to fuse by adjustment of mirror  $M_6$ , and the double images appearing at a distance from  $S_2$  were made to fuse by rotating  $S_2$ . When both images appeared fused,  $S_2$  was at angle  $\theta/2$ . The infinite fringe was visible in sodium light. By alternate rotations of  $M_6$  and  $S_2$ , fringes of the desired spacing and orientations were focused to appear virtually in the tunnel. The camera was put back into place and fringes appeared on the ground glass.

To obtain white-light fringes, it is necessary to establish zero optical path difference between the two interfering beams for all wavelengths. It was found experimentally that chromatic aberration of the glass of the splitter plate was compensated by a window of equal thickness introduced in each conversion unit (fig. 4). A 6-volt microscope illuminator lamp was substituted for the B-H6 lamp at the source. The ground glass of the camera was removed and a spectroscope capable of two angstrom resolution was placed with its slit at the focal plane of the camera. When the optical path difference of the two beams did not exceed 1 millimeter, many fringes were visible in the white-light spectrum seen through the eyepiece. By translating  $M_6$  in the correct direction and readjusting  $M_6$  and  $S_2$  to maintain focus of the fringes, the fringes became fewer in number. When only one or two fringes were seen over the spectrum, the zero path difference adjustment was attained and white-light fringes appeared on the ground glass of the camera. When the optical path difference of the two beams exceeded 1 millimeter, fringes in the white-light spectrum could not be seen and it was necessary to translate  $M_6$  in one direction or the



other until the path difference was within 1 millimeter and the spectro-scope test could be used. With the large translation of  $M_6$  in such cases, it was necessary to readjust for sodium-light fringes. However, the total time required for adjustment did not exceed the time required for a Mach-Zehnder interferometer in the same condition.

As shown in figure 1, an ideal adjustment of the optical system would cause an overlapping of every pair of coherent rays. Distortions, however, caused by the off-axis parabolic mirrors were additive and prevented precise overlapping of all pairs of rays at the plane of the camera. As a result, with an extended light-source aperture, the fringe contrast became so poor over part of the image that fringes were not visible. A similar condition of the interfering rays was encountered by Bates in another new-type interferometer (reference 4). A method is given in reference 4 for computing the fringe visibility as a function of the source dimensions. A restricted source aperture of 0.03-inch diameter was found to compensate for the distortion effect and provides good fringes over the entire working field. These fringes are shown in figure 5, which was exposed with a 10-microsecond flash of a B-H6 mercury lamp filtered for the green mercury line. The image was too large for adequate exposure. An image one-half as large, on a 4- by 5-inch negative, would have provided a satisfactory exposure.

Figure 5 shows the fringe configuration that results when a lamp is placed in the tunnel. The fringe curvature in the undisturbed part of the field is characteristic of this two-mirror off-axis system. Two metal rods visible in the field are part of a model support structure in the test beam. The disturbance of the fringes caused by room-air convection was prevented by using an enclosure of rubberized cloth on a wood frame erected around the light path.

The installation was located on the second floor of a four-story reinforced concrete frame building. The parabolic mirrors, source, and camera pedestals were individually mounted upon the floor, which served as the frame of the interferometer. The tunnel was supported by an independent structure not attached to the building. When the tunnel was not in operation, building vibration displaced the fringe pattern erratically across the viewing screen with an amplitude of about one fringe. Ease of adjustment was not affected by this motion. No fringe displacement was noticed when persons walked about the room. During tunnel operation the fringes became difficult to see on the viewing screen and precise adjustments were difficult to make. This was caused partly by building vibration amplified by the noticeable lack of rigidity in the pedestals and partly by unsteady air flow, as inferred



from high-speed movies that were taken. The short duration of exposure eliminated the vibration-caused blurring in the photographs. Several successive frames from a 16-millimeter high-speed movie are shown in figure 6, where the fringes are seen to have random kinks of about  $1/2$ -fringe amplitude caused by unsteady air flow.

The conversion unit can, in general, be operated with any schlieren system. A single-mirror schlieren shown in figure 7 is a simple arrangement that requires only one conversion unit. The compensator window is relocated next to the splitter plate. The size of the light source is not so limited as it is with the two-mirror off-axis schlieren. Interference fringes for a single-mirror schlieren taken with a 16-inch-diameter spherical mirror with 80-inch radius of curvature are shown in figure 8.

#### SUMMARY OF RESULTS

An interferometer utilizing 24-inch-diameter schlieren mirrors has been operated successfully with an 18- by 18-inch supersonic tunnel.

Illumination of the camera image was sufficient to expose either a 16-millimeter high-speed motion picture with continuous illumination from the B-H6 lamp or a 4- by 5-inch film with a 10 microsecond flash of the B-H6 lamp.

Although the components of the interferometer were independently mounted upon the floor of the building, vibration did not seriously affect the ease of adjustment of the instrument or affect the quality of the photographs. The fringe configuration is considered regular enough to permit measurements.

Lewis Flight Propulsion Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio.



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4. Bates, W. J.: A Wavefront Shearing Interferometer. Proc. Phys. Soc., vol. 59, Pt. 6, no. 336, Nov. 1947, pp. 940-950.



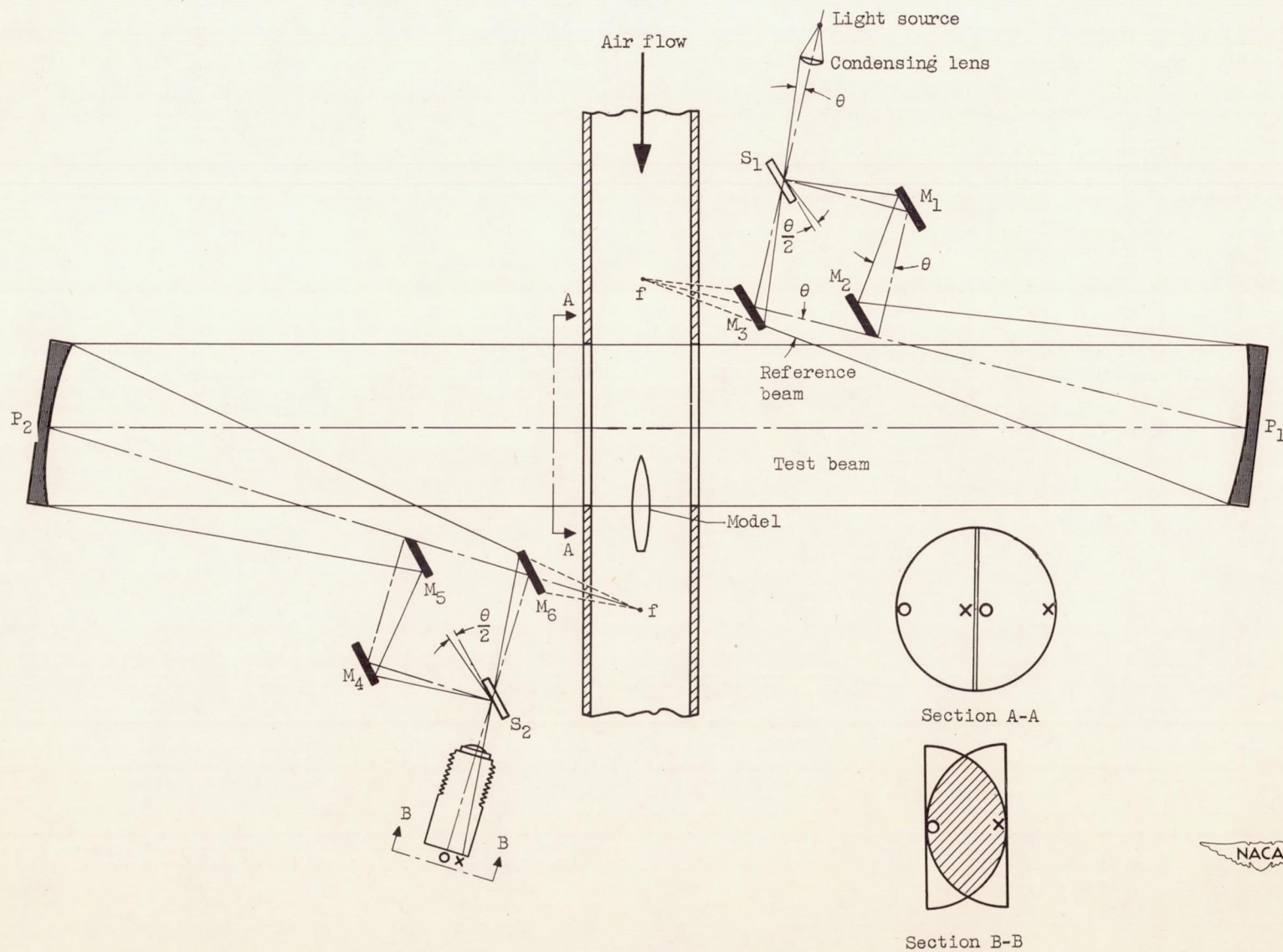


Figure 1. - Two-mirror schlieren as an interferometer.



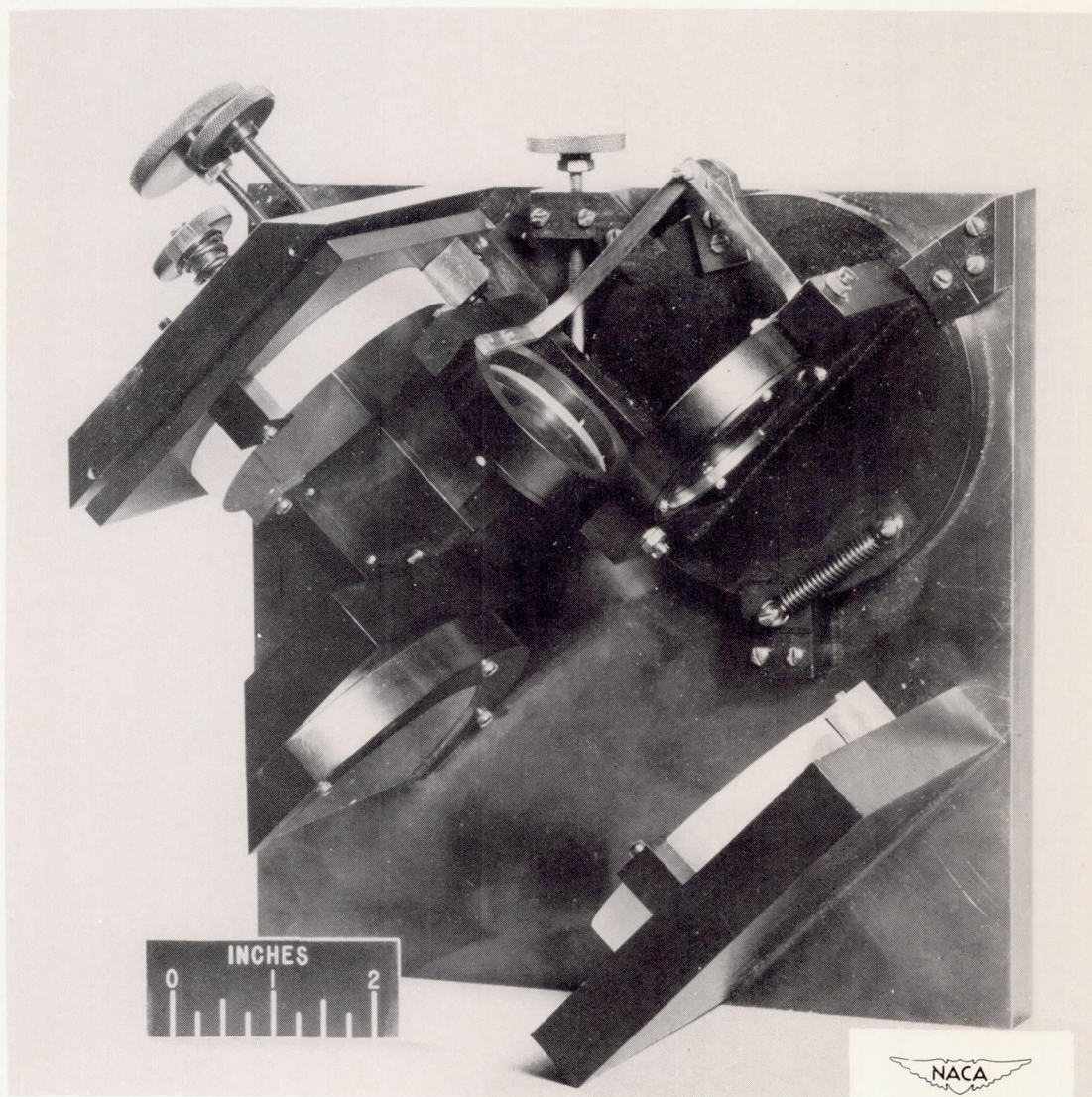
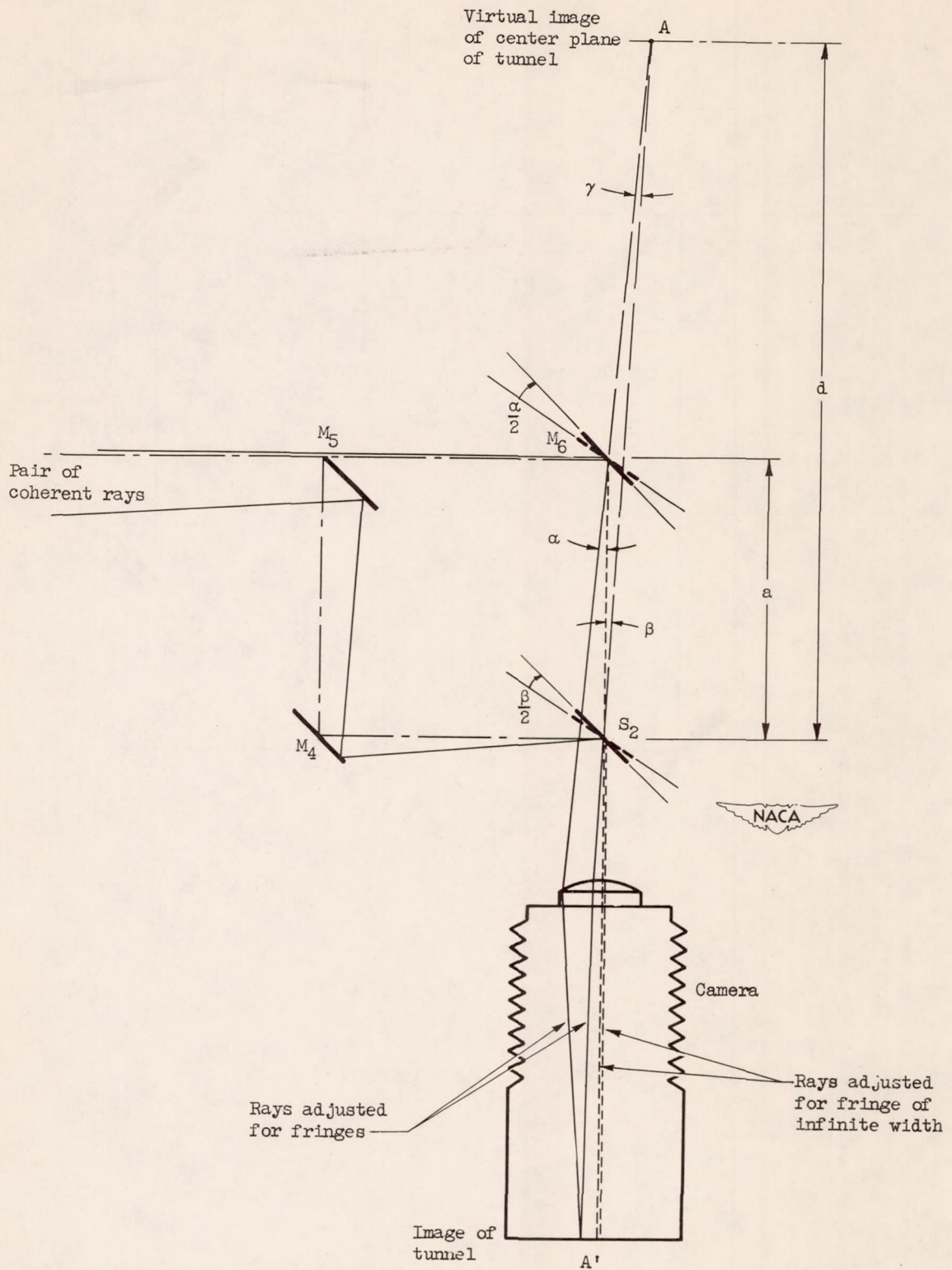


Figure 2. - Interferometer conversion unit.









36 Figure 3. - Adjustment of conversion unit for fringes.

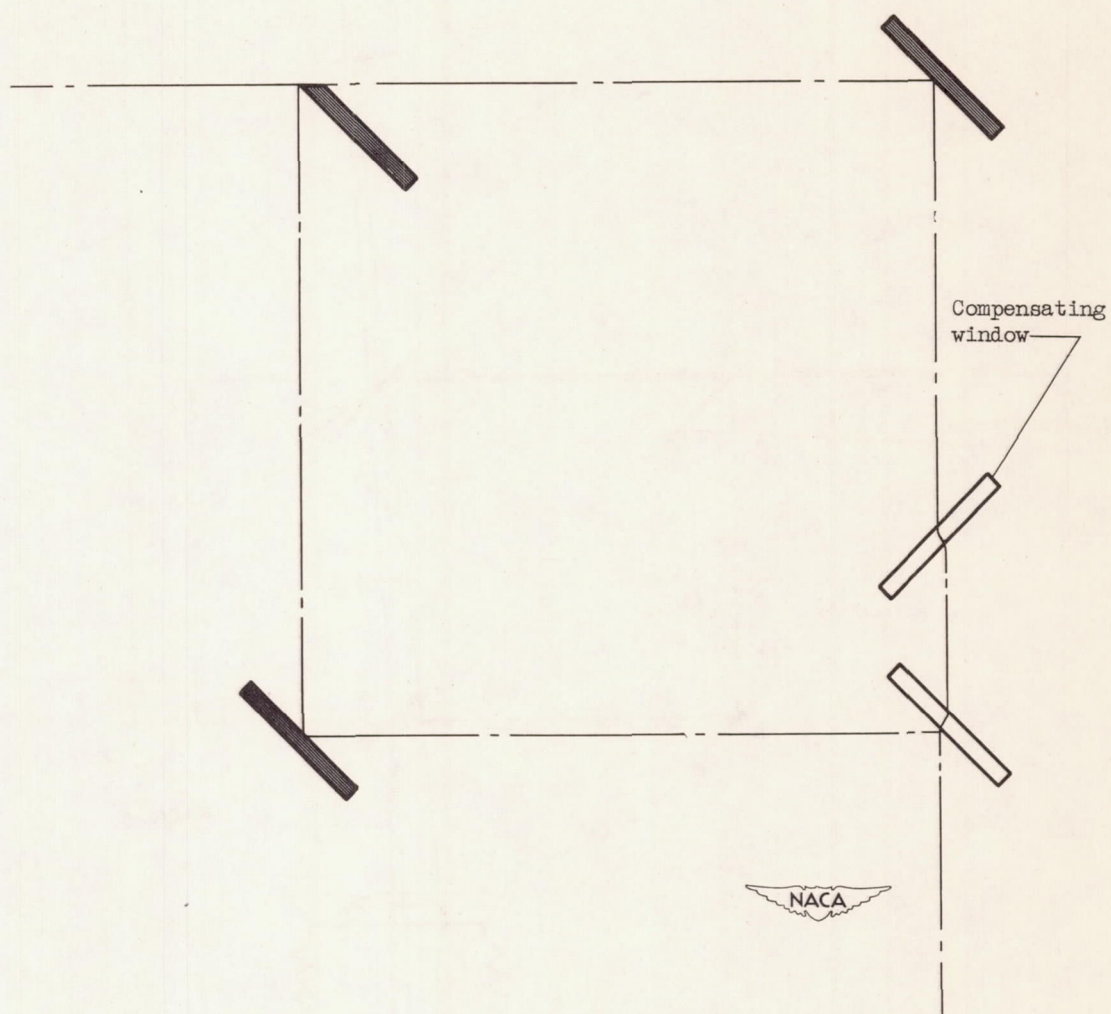


Figure 4. - Compensating window in conversion unit.



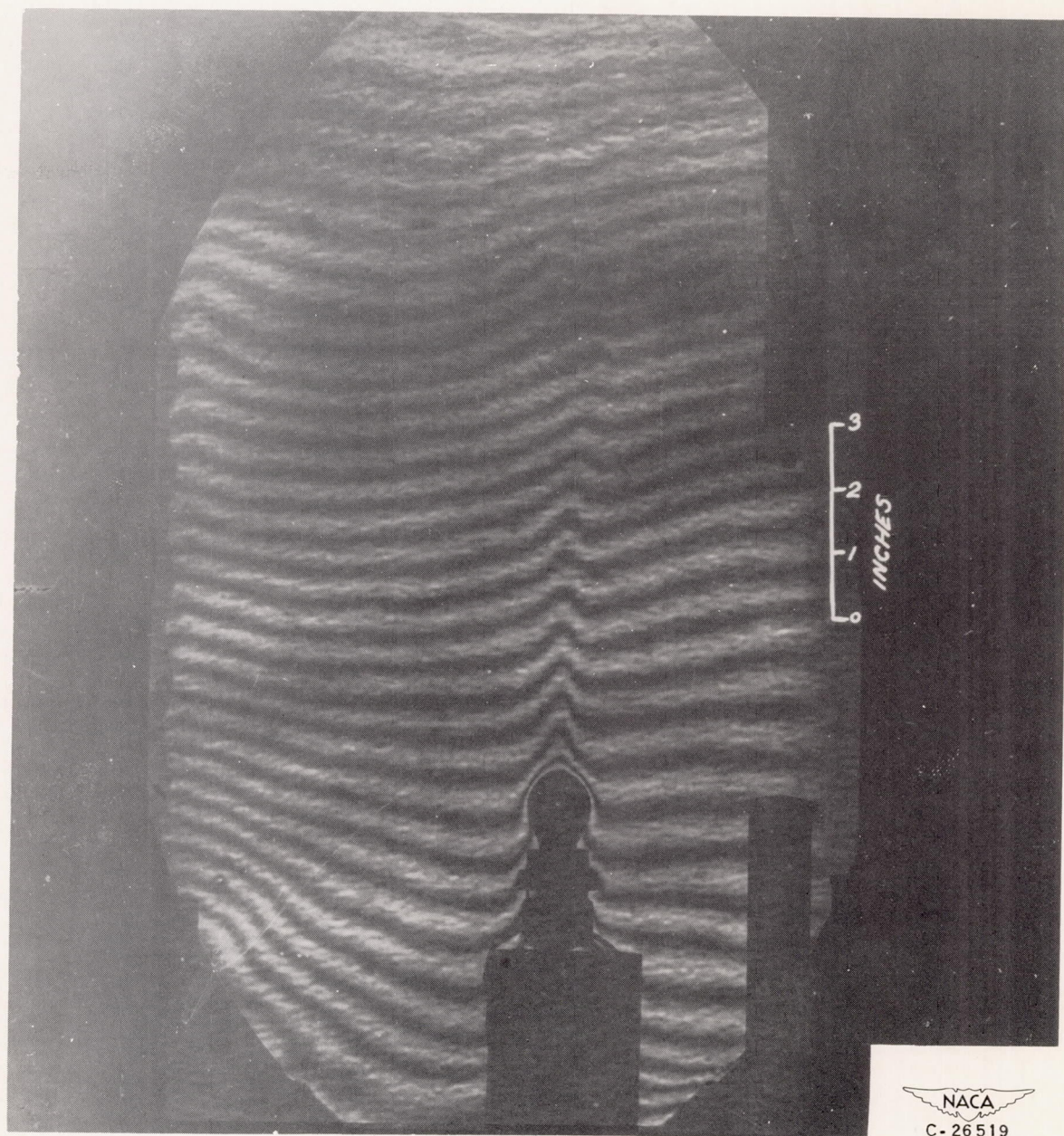
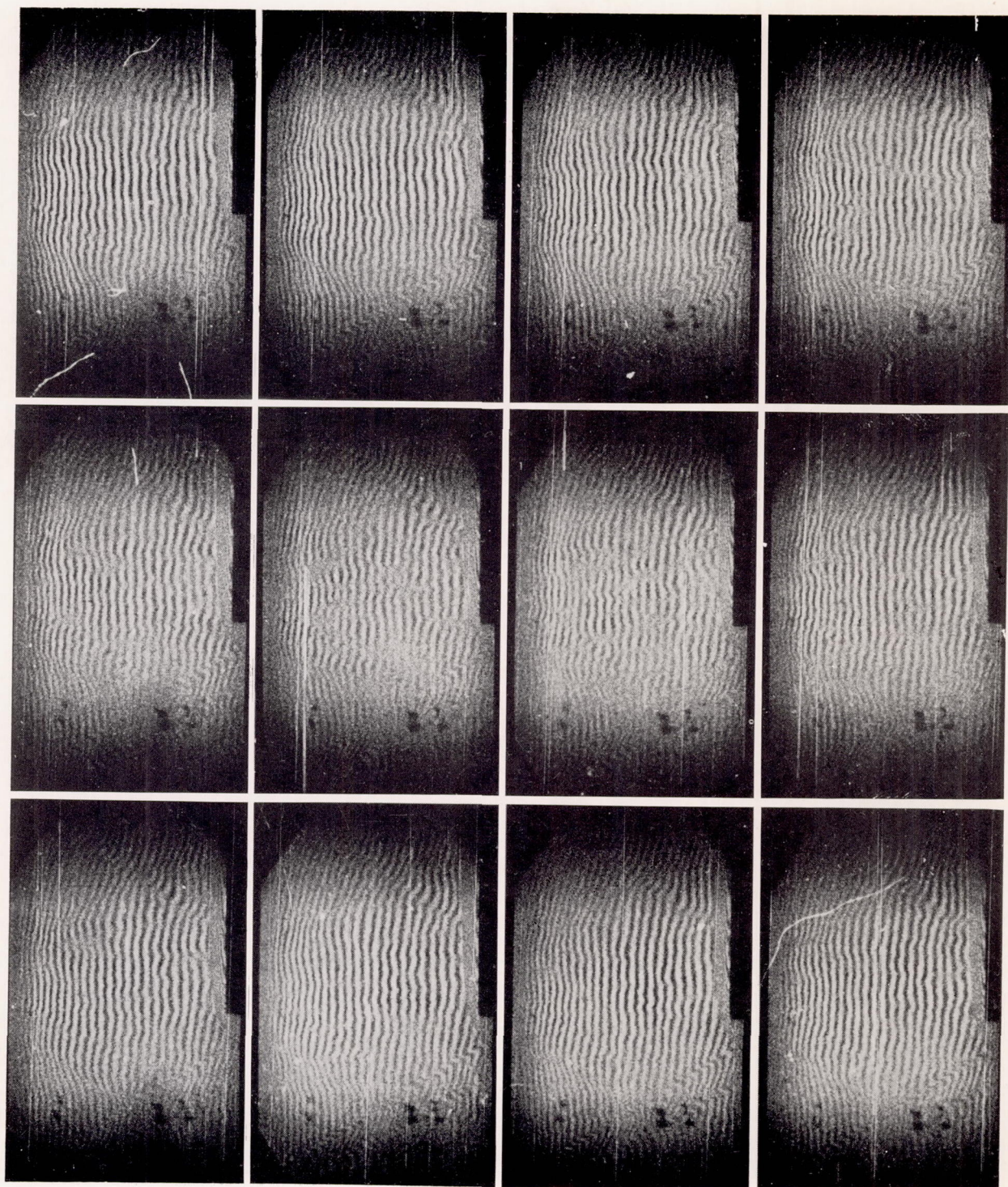


Figure 5. - Interference fringes of 18- by 18-inch tunnel.







— Air flow  
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Figure 6. - Successive frames from high-speed movie of 18- by 18-inch tunnel with air flow. (1000 frames/sec)





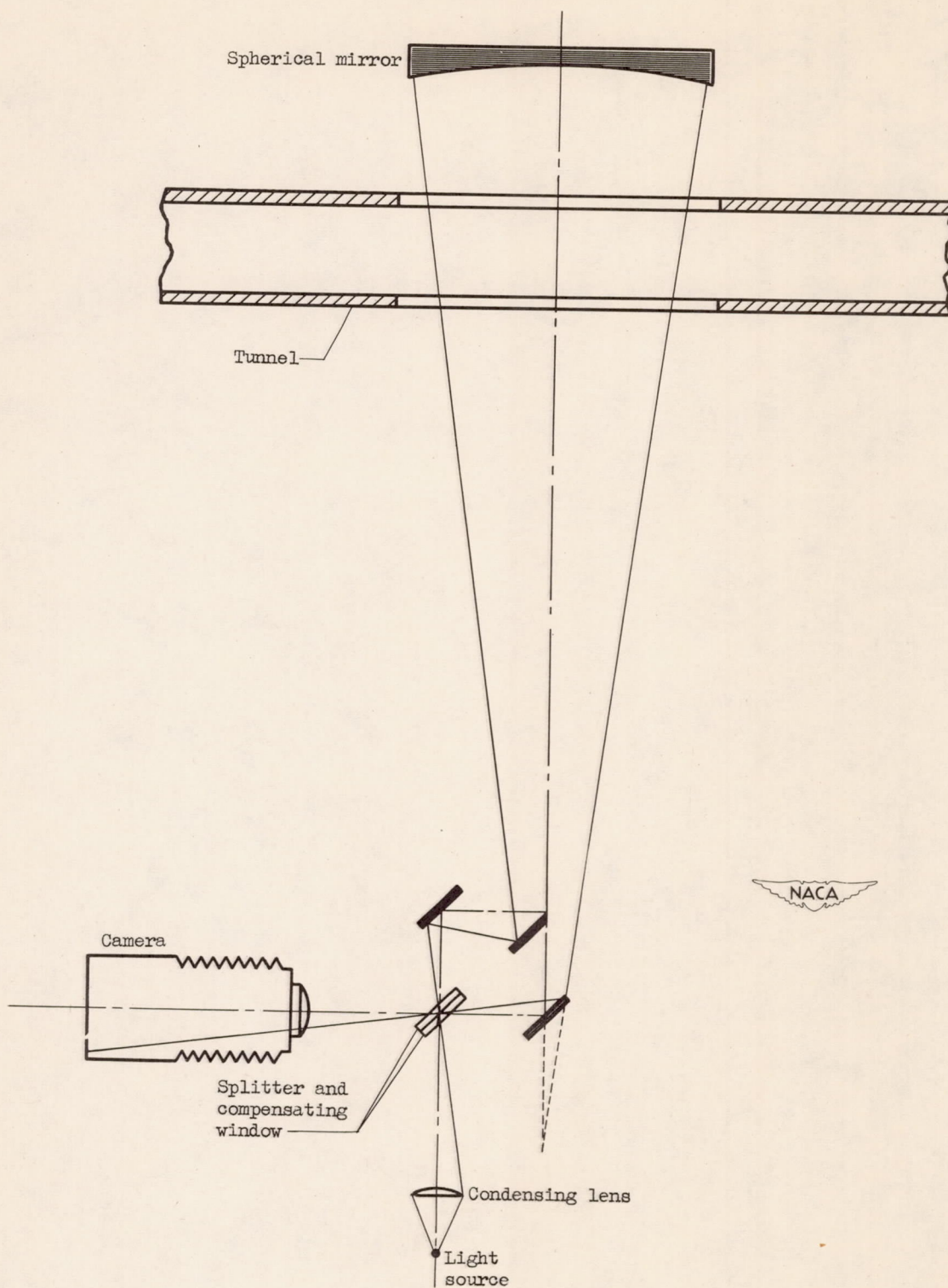


Figure 7. - Single-mirror schlieren as an interferometer.







Figure 8. - Interference fringes with single-mirror schlieren.